SOIL-WATER CHARACTERISTIC CURVE FOR SPV 200

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ABSTRACT

Clays are one of the alternatives used in the management of wastes disposal at landfills. Clays act as environmental barriers around waste disposal site where they are used as liners and capping materials for landfills sites. The clay liners act as barriers to water and containment flow in landfills and other waste containment facilities. Clays are used because of its hydraulic properties that is the soil-water characteristic curve (SWCC). This study focuses on the laboratory tests to measure the water retention characteristics of SPV 200 Bentonite. Bentonites have been considered due to their low permeability, high sorption capacity, self-sealing characteristics, and durability in a natural environment. Standard soil tests were conducted to determine the physical properties of the SPV 200. Two available technique that are osmotic technique and vapor equilibrium technique (VET) were used to establish the suction-water content SWCC curves. The osmotic technique is related to the osmosis principle where the water and salt exchanged to achieve equilibrium. This technique measure the matric suction occurred in the clay specimens. The suction is induced by the PEG 20 000 solutions where the suction ability is determined by the concentration. In VET, the clay specimen of SPV 200 are placed in closed thermodynamic environment containing aqueous solution of given alkaline salt solutions. Water exchanges occur by vapor transfer between the salt solution and clay specimen. Suction is applied to specimen when vapor equilibrium is achieved. The graphs of water content over varying suctions and water content over elapsed time are establish for each technique and then combine to show the curve of the drying process ranging from low suction to high suction value. In conclusion, SPV 200 bentonite has a swelling properties where it can absorb a lot of water and increase its volume, but when suction applied, the volume decreased as it experience a great loss in water content.

ABSTRAK

Tanah liat adalah salah satu alternatif yang digunakan dalam pengurusan sisa pelupusan di tapak pelupusan. Tanah liat bertindak sebagai lapisan penghalang semula jadi di sekitar tapak pelupusan sampah di mana ia digunakan sebagai lapisan perlindungan bagi tanah dan lapisan yang melitupi bahan-bahan buangan di tapak pelupusan tapak. Lapisan tanah liat bertindak sebagai penahan aliran air di tapak pelupusan dan juga di kawasan sisa buangan yang lain. Tanah liat digunakan kerana sifat hidrauliknya iaitu lengkungan hubungkait tanah dan air. (SWCC). Kajian ini memberi tumpuan lebih kepada ujian makmal untuk mengukur ciri-ciri pengekalan air bagi SPV 200 Bentonit. Bentonit digunakan kerana kebolehtelapan yang rendah, kapasiti penyerapan yang tinggi, ciri-ciri diri kedap, dan ketahanan dalam persekitaran semula jadi. Ujikaji tanah telah dijalankan untuk mengetahui sifat-sifat fizikal SPV 200. Dua teknik iaitu teknik osmosis dan teknik keseimbangan wap (vet) telah digunakan untuk mendapatkan lengkungan hubungkait tanah dan air (SWCC). Teknik osmosis menggunakan prinsip osmosis di mana pertukaran antara molekul-molekul air dan garam berlaku untuk mencapai keseimbangan. Teknik ini memberi tekanan sedutan matrik yang berlaku pada spesimen tanah liat. Daya tekanan dihasilkan oleh larutan PEG 20 000 di mana keupayaan sedutan ditentukan oleh kepekatan larutan itu sendiri. Dalam VET, spesimen tanah liat SPV 200 diletakkan di dalam persekitaran termodinamik tertutup yang mengandungi larutan garam beralkali. Pertukaran molekul air berlaku disebabkan pemindahan wap antara larutan garam dan spesimen tanah liat. Daya tekanan dikenakan ke atas sampel apabila keseimbangan wap dicapai. Graf hubungkait antara kandungan air dengan daya tekanan yang berbeza dan juga perubahan masa dihasilkan untuk setiap teknik dan kemudian kedua-duanya digabung untuk menunjukkan lengkungan proses pengeringan antara julat nilai daya sedutan rendah kepada julat nilai sedutan tinggi. Kesimpulannya, SPV 200 bentonit mempunyai ciri-ciri pembengkakan di mana ia boleh menyerap banyak air dan meningkatkan isipadu, tetapi apabila daya tekanan sedutan dikenakan, jumlah isipadu berkurangan kerana ia mengalami kehilangan besar dalam kandungan air.

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Ψ	Total Suction
θ	Volumetric Water Content
ρ_d	Dry Density
ρ_w	Density of Water (1.0 $Mg.M^{-3}$)
γ_w	Unit Weight of Water (9.81 kNm^{-3})
e	Void Ratio
g	Acceleration Due to Gravity (9.81 ms^{-2})
H	Relative Humidity
M	Molecular Weight of Water (0.018kg $mole^{-1}$)
R	Universal Gas Constant (8.317 J $mole^{-1}$ deg^{-1})
s_r	Degree of Saturation
T	Absolute Temperature (°K)
w	Water Content (Gravimetric)

LIST OF ABBREVIATIONS

ASTM	American Society for Testing Materials
ATC	Air-Tight Chamber
BS	British Standard
GCL	Geosynthetic Clay Liner
LOI	Loss on Ignition
PEG	Polyethylene Glycol
SWCC	Soil Water Characteristic Curve
VET	Vapor Equilibrium Technique

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Due to the increasing population and rapid development of the world, the amount of waste generated continues to increase. Less than 5% of the waste is being recycled and this will cause a massive amount of waste disposal to the landfills. Despite the continuously increase of waste disposal, the waste management standards are still poor. These include the inefficient storage and collection system, poor management of municipal wastes with toxic and hazardous waste disposal and inefficient utilization of disposal site space in landfills. These will lead to the contamination of soil at the landfill. The ammonia gas produced from the waste will also cause air pollution to the surrounding. One of the alternatives used to solve the problems is by using the natural sources that are clays. Clays act as environmental barriers around waste disposal site where they are used as liners and capping materials for landfills sites. The clay liners act as barriers to water and containment flow in landfills and other waste containment facilities. Highly plastic clays are used as barriers in landfills and nuclear waste repository (Daniel, 2003; Pusch, 2005). Furthermore, clays also used for geo-environmental application in remediation, treatment and control of waste (Sharma & Reddy, 2004).

Clays are used for barriers because of its hydraulic properties. One of the hydraulic properties is the soil-water characteristic curve (SWCC), which shows the relation between matric suction and water content. SWCC can be used to estimate the soil properties such as volume change characteristic, permeability and shear strength functions (Fredlund, 2006).

This research study focuses on the laboratory tests to measure the water retention characteristics of SPV 200 Bentonite clay. Bentonites have been considered due to their low permeability, high sorption capacity, self-sealing characteristics, and durability in a natural environment (Pusch, 1982; Muller-Vonmoos et al., 1994; Romero, 1999; Pusch and Yong, 2005; Plotze et al. 2007).

1.2 PROBLEM STATEMENT

The suction-water content soil-water characteristic curves (SWCCs) provide useful information for predicting the engineering behaviour of soils (shear strength, volume change behaviour, and permeability). It is very important to establish the suction-water content SWCC of soils. SPV200 is an alternative form of MX80 bentonite which is considered as reference material for bentonite. Bentonite is being used in many engineering applications particularly in geo-environmental engineering application, thus establishing the wetting and drying suction-water content SWCC for SPV200 is very useful for predicting its engineering behaviour.

1.3 OBJECTIVE OF STUDY

There are two objectives in this study that are:

1) To determine the physical properties of SPV 200.

2) To establish drying suction-water content SWCCs for SPV 200.

1.4 SCOPE OF STUDY

In this research, we will study the water retention behaviour of the bentonite clay. The bentonite clay that is SPV 200 from US will be considered in this study. SPV 200 is a type of sodium bentonite. It is a hydrous aluminum silicate comprised principally of the clay minerals montmorillonite. It contains a small portion of feldspar, calcite and quartz. In order to get the SWCC, drying and wetting tests will be conducted for suction applied of 0.1 MPa – 300 MPa using osmotic and vapor equilibrium techniques.

1.5 THESIS LAYOUT

This thesis consists of five consecutive chapters. Chapter 2 presents the literature review conducted that are related to this research study. This chapter includes application of bentonite, clay mineralogy, soil suction and water retention behaviour.

Chapter 3 is methodology. This chapter explains the methodologies adopted in this study. This chapter covers all steps and procedures required for the sample preparation, determination of bentonite clay properties (specific gravity, initial water content, Atterberg limit, particle size distribution and soil mineral properties), and determination of drying and wetting behaviour in bentonite clay.

Chapter 4 consists of results and discussion obtained from the study. This chapter includes the outcome obtained through the tests done in the determination of bentonite properties. It also include the results obtained from the wetting and drying process of the bentonite clay which are then will be used to discuss the behaviour of suction in bentonite clay, and to develop the SWCC.

Chapter 5 is the conclusion and recommendations. This chapter summarizes the whole purpose of this study, the significance and important of this study for future references.

CHAPTER 2

LITERATURE REVIEW

2.1 APPLICATION OF BENTONITE CLAY

Bentonite is a well-known sealing material which have a various purposes on engineering works for example in the construction of foundation, hydraulic engineering and also on landfill construction, especially for encapsulation of old waste deposits. Bentonite has the physical, structural and chemical properties which make them very reliable to be used as the material to protect the environment against the negative effect of dumping grounds (Koch, 1989). The most important properties for bentonite used in geotechnical applications (IBECO, 1998) are the swelling behavior caused by adsorption of water molecules at the interlayer cations and at the clay mineral surface, the cations exchange capacity and the very small particle size compared with other clay minerals like illite or kaolinite.

One of the most important applications is bentonite as a sealing and adsorptive component in mineral liners for landfills. For the various civil engineering construction techniques, bentonite is used either in form of a water-based slurry, as a powder or in granular form (Koch, 1989). Dry bentonite and soil are mixed together with a very powerful soil milling machines to produce mineral barriers for base and cap seals of landfills. In recent years, job sites were done using a mixed-in-plant-system, where a mixture of one or two soils as a base material is enriched with a clayish mineral, like bentonite or kaolinite, to obtain very homogenous products. Bentonite is the only sealing materials that can be legally used in waste dumping areas and for the encapsulation of contaminated areas. It often used in the horizontal technical base liner and vertical cut-off walls. For horizontal technical base liners, the adsorption ability, the ion exchange capacity and the swelling behavior of bentonite is important. For cut-off walls, bentonite controls the rheological behavior of the slurry and is responsible for the low permeability of the hardened bentonite-cement-wall.

Bentonites have been applied for clay cores of dams, lining ponds and lakes and these applications are widely practice in the USA. Bentonites were introduced in various foundation engineering works for example grouting, cut-off walls and diaphragm walling (Koch, 1989). The development of the diaphragm-walling methods by Veder in 1950 brought a significant growth in the use of bentonite for civil engineering (Veder, 1950, 1953, 1975). After the development of the diaphragm walling, there is a new invention called sealing walls, which are made with bentonite-cement-filler-mixes and were built since the mid-1970s. The sealing walls mainly used for containment of contaminated land. In Germany, bentonites were used for lining of landfills since early 1980s. The purpose is to minimize the hydraulic conductivity of minerals liners. Years after, Geosynthetic Clay Liner (GCL) was introduced. It is a thin and flexible lining membrane that is used on the construction of landfills (Koch, 1989).

Besides the landfill construction engineering, the application of bentonites also can be applied on the reclamation of old industrial areas and disused mining sites. The excavation of contaminated soil, mixing with an adsorptive mineral and re-installation is one of the alternatives, which allows retaining the natural soil functions while immobilizing the pollutants (Koch, 1989). The possible application of bentonites is in the field of groundwater decontamination with passive systems for in-site clean-up. By using a tunnel-shaped arrangement of cut-off walls with permeable flow-through areas (tunnel-and -gate systems) or by using permeable reactive walls, contaminated groundwater percolates through sorptive or precipitating agents for the purpose of pollutant adsorption or chemical treatment (Starr and Cherry, 1994).

2.2 CLAY MINEROLOGY

Aluminum silicates are a complex element in clay composed of two basic units that are silica tetrahedron and alumina octahedron. Figure 2.1 shows that each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom.

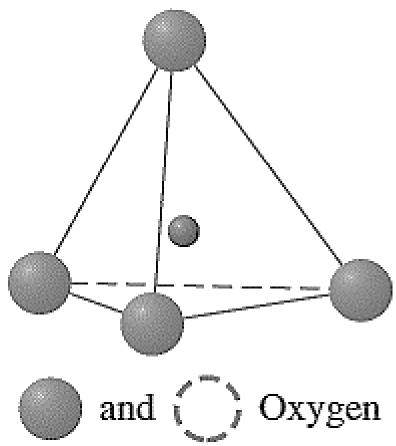

Figure 2.1 Silica Tetrahedron (After Grim, 1959)

Silica sheet is formed when the tetrahedral silica units combined together as shown in Figure 2.2. At the base of each tetrahedron, the three oxygen atoms are shared by neighboring tetrahedral.

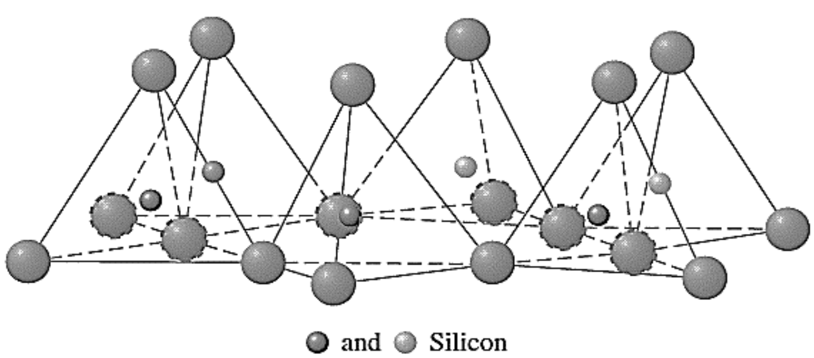

Figure 2.2 Silica Sheet (After Grim, 1959)

The octahedral units consist of six hydroxyls surrounding an aluminum atom as shown in Figure 2.3 and the combination of the octahedral aluminum hydroxyl units gives an octahedral sheet. Aluminum atoms may be replaced by magnesium in the octahedral units and in this case the octahedral sheet is called a brucite sheet. Each silicon atom with a positive charge of four is linked to four oxygen atoms with a total negative charge of eight in a silica sheet. But each oxygen atom at the base of the tetrahedron is linked to two silicon atoms. This means that the top oxygen atom of each tetrahedral unit has a negative charge of one to be counterbalanced. When the silica sheet is stacked over the octahedral sheet, as shown in Figure 2.4, these oxygen atoms replace the hydroxyls to balance their charges.

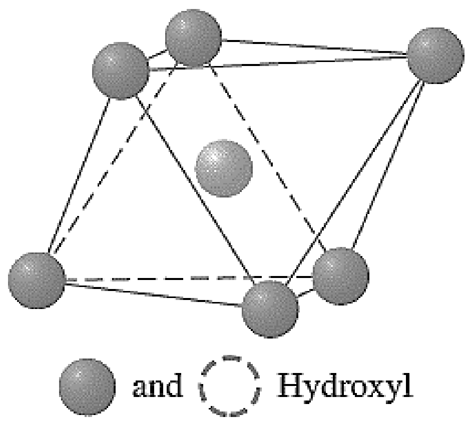

Figure 2.3 Alumina Octahedron (After Grim, 1959)

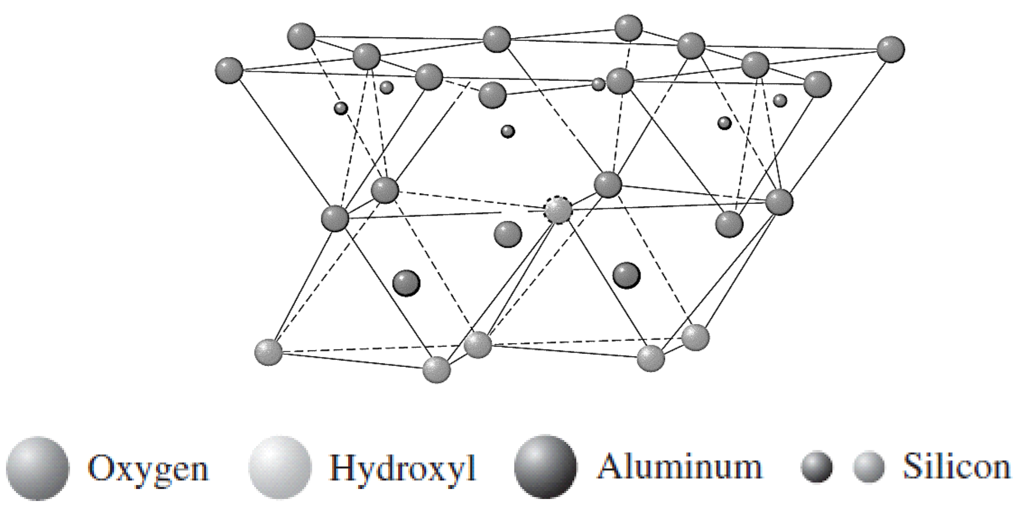

Figure 2.4 Elemental Silica-Gibbsite Sheet (After Grim, 1959)

Bentonite is a type of montmorillonite clay. Montmorillonite is one gibbsite sheet sandwiched between two silica sheets as shown in Figure 2.5 and Figure 2.6. In montmorillonite there is isomorphous substitution of magnesium and iron for aluminum in the octahedral sheets (Das, 2010). Potassium ions are not present as in illite, and a large amount of water is attracted into the space between the layers. Particles of montmorillonite have lateral dimensions of 1000 to 5000 Å and thicknesses of 10 to 50 Å. The specific surface is about 800 m^2/g.

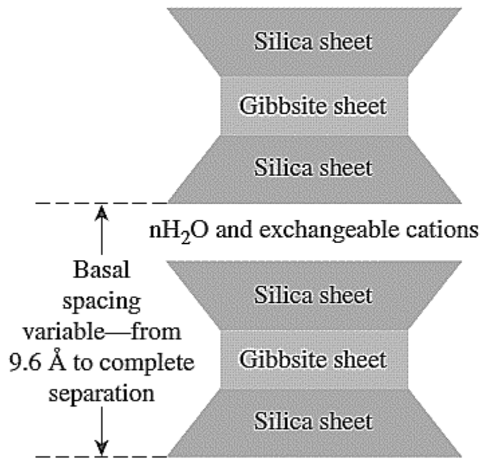

Figure 2.5 Diagram of the structure of montmorillonite (Das, 2010)

A net negative charge can be found on the surfaces of the clay particles. This is due to the isomorphous substitution and of a break in continuity of the structure at its edges. Larger specific surfaces can produce larger negative charges. Apart of that, some positively charged sites also occur at the edges of the particles.

The negative charge is balanced by exchangeable cations like Ca^{2+}, Mg^{2+}, and K^{+} surrounding the particles being held by electrostatic attraction in dry clays. These cations and a few anions float around the clay particles when water is added to clay. This configuration is referred to as a diffuse double layer. The cation concentration decreases with the distance from the surface of the particle.

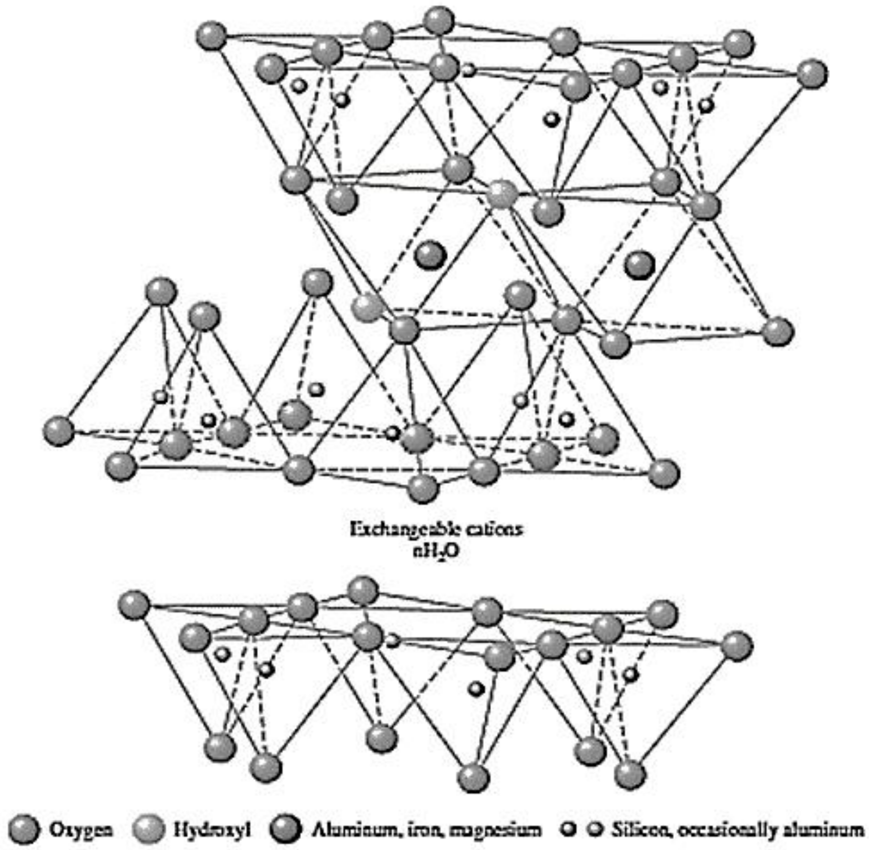

Figure 2.6 Atomic Structure of Montmorillonite (Das, 2010)

Water molecules are polar. Hydrogen atoms are not axisymmetric around an oxygen atom but instead they occur at a bonded angle of 105°. As a result, a water molecule has a positive charge at one side and a negative charge at the other side. It is known as a dipole.

The negatively charged surface of the clay particles and the cations in the double layer attracted the dipolar water. Whereas, the soil particles are attracted the cations. Hydrogen bonding is a third mechanism by which water is attracted to clay particles where hydrogen atoms in the water molecules are shared with oxygen atoms on the surface of the clay. Some partially hydrated cations in the pore water are also attracted to the surface of clay particles. These cations attract dipolar water molecules. All these possible mechanics of attraction of water to clay are shown in Figure 2.7. The force of attraction between water and clay decreases with distance from the surface of the particles. Double-layer water occurs when all the water held to clay particles by force of attraction. The innermost layer of double-layer water, which is held very strongly by clay, is known as adsorbed water. This water is more viscous than free water is.

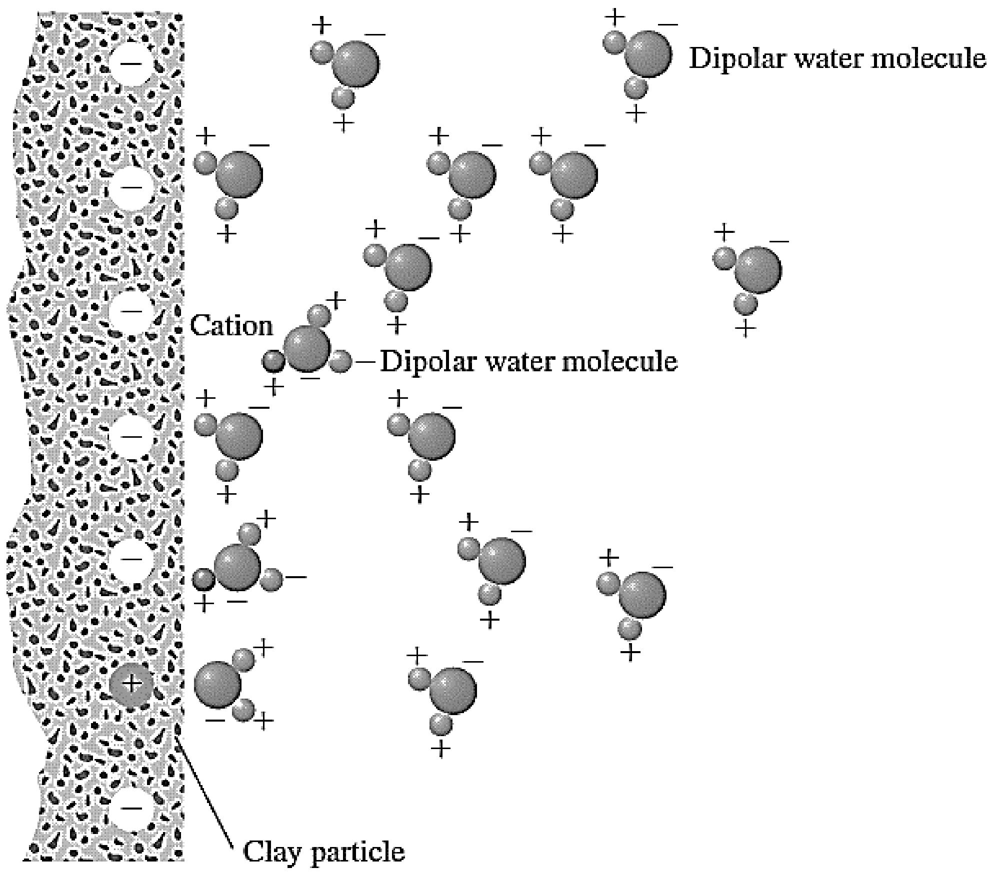

Figure 2.7 Attraction of dipolar molecules in diffuse double layer (Das, 2010)

The plastic properties of the clay soils are due to the orientation of water around the clay particles. It needs to be well recognized that the presence of clay minerals in a soil aggregate has a great influence on the engineering properties of the soil. The present of moisture in clay influenced the engineering behavior of a soil as the percentage of clay mineral content increases. For all practical purposes, when the clay content is about 50% or more, the sand and silt particles float in clay.

2.3 SOIL SUCTION

2.3.1 Components of Suction

There are two components of soil suction that are matric suction and osmotic suction, which also known as solute suction. The total suction is the sum of both matric and osmotic suction. Matric suction is due to surface tension at the interfaces between the water and gas phases present in unsaturated soil (Huat, 2012). The surface tension effect is also referred to as capillary. Osmotic suction is due to the presence of dissolved salts within the pore water. The negative pressure must be applied to a pool of pure water at the same elevation and temperature to achieve equilibrium with the soil water and this clearly defined the concepts of total suctions.

The suction force acting within the soil due to capillary (matric suction) and suction induced by the different concentration of dissolved salts in the pore water and the pure water outside (osmotic suction) will be balanced by the negative pressure. Water will try to flow from pure water outside to soil water in order to equalize the differences in salt concentration, thus trying to draw water into the soil and inducing suction. If the pure water (that is in contact with the soil) and the soil water are of the same composition, hence there will be no osmotic suction and the negative pressure needed to achieve equilibrium would be equal to the matric suction only. This can be explained further with the help of Figure 2.8.

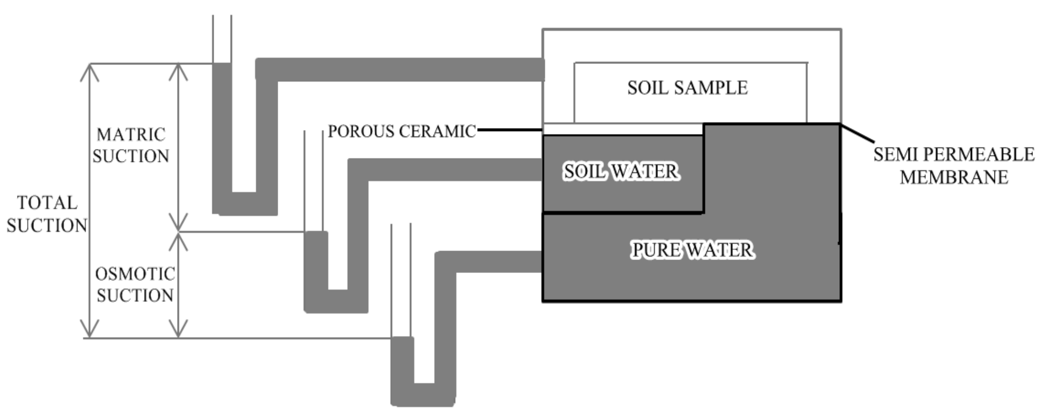

Figure 2.8 Components of Total Suction: Matric and Osmotic Suction

(After Huat, 2012)

In the figure, the soil sample is separated from water by a porous ceramic which allows salts to pass through freely. In this case, salts will move through the ceramic until equilibrium is established between the salt concentrations in the sample and the water beneath the ceramic. Since the composition of the water on the other side of the ceramic will be the same as the soil water, there will be no osmotic suction component and the pressure differences across the ceramic will then be equal to the matric suction (Huat, 2012).

In other situation, where there is semi-permeable membrane that separates the water beneath the ceramic and the pure water, the difference in pressure across the membrane will be equal to the osmotic suction. This membrane only allows water to pass through but prevents the passage of salts. Therefore, where the soil sample is separated from the pure water by the semi-permeable membrane, the pressure difference across the membrane between soil and pure water will be equal to the total suction as both osmotic and matric suction components are present (Huat, 2012).

2.3.2 Suction Control Technique

2.3.2.1 Axis Translation Technique

There are three method that are available to control suction (axis-translation method, osmotic technique and vapor control technique) (Lu, 2004). In axis-translation method, the pressure difference across the water/air interface is the parameter that controls the matric suction. To express in formula, u_a is the pore air pressure and u_w is the pore water pressure. The pressure difference will be u_a-u_w. However, the pore air pressure u_a is at atmospheric pressure state which make it become u_a=0. Refer to this, the pressure difference now will be $-u_w$. This is what we call negative pore water pressure. As the conclusion, the suction is defined as the negative pore water pressure $-u_w$. If the pore water pressure becomes too negative, it will make it difficult to measure it directly as the cavitation can occur in conventional measuring system. Cavitation is the process by which bubbles form when water is subjected to tensile stress (Huat, 2012).

Therefore, to solve this problem, suctions are measured in the laboratory by elevating the pore air pressure, u_a within the sample. This technique is called axis translation. The pressure difference remains unchanged by shifting the axis of pressure. In this technique, the